Report on Cyclotron Experiment

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Cyclotron

Description

This experiment simulates a kind of particle accelerator called a cyclotron. A cyclotron operates by applying an alternating electric field between two D-shaped metal structures referred to as "Dees". This causes a static particle between the Dees to enter one of the Dees where it is then shielded from the electric field, but exposed to a magnetic field within the Dee. This magnetic field causes the particle's trajectory to rotate so that it then leaves the Dee and reenters the electric field, increasing its velocity and thus putting it in a wider and wider spiral until the particle exits the cyclotron entirely.

This experiment allows the user to observe the effects of adjusting the frequency at which the electric field oscillates in the cyclotron. It also allows the user to change the initial velocity of the particle, the charge and the mass.

How to use it

Along the top of the simulation window, the editable fields for the values of charge, x and y components of the velocity are shown, along with the play/pause and reset buttons. The cyclotron frequency is the field displayed at the bottom of the window. A plot of the kinetic energy can be shown by clicking the "Kinetic Energy Plot" checkbox at the bottom of the screen.

How it works

Variables

- Var table
  - b is the magnetic field vector.
  - *x, y* are the x and y positions of the particle.
  - *vx, vy* are the velocity of the particle in the x and y directions respectively.
  - q is the charge of the particle in the simulation. It is initially set to 1, so that the particle acts as a proton.
  - m is the mass of the particle in the simulation.
  - t is the time variable of the system.

- Plotting
  - *ke* is the kinetic energy of the system, given by $ke = \frac{1}{2}mv^2$.
  - *fx* is the force acting on the particle in the x direction due to the magnetic field.
  - *fy* is the force acting on the particle in the y direction due to the magnetic field.
  - *showPlot* is the variable behind the "Kinetic Energy Plot" checkbox.
- E field
  - *e* is the electric field vector.
  - *freq* is the frequency at which the electric field direction oscillates.
  - *amp* is the magnitude of the electromagnetic field.
- Semicircle
  - *semiCircX* is the array of points used to plot one of the Dees along the x-axis.
  - *semiCircY* is the array of points used to plot one of the Dees along the y-axis.
  - *r* is the radius of the semicircle.

Initialisation

The initialisation section of the simulation is used to populate the arrays of points which are used to plot the semicircle using the custom method *getX*.

Evolution

The evolution page sets up a couple of ODEs such that the rate and which x and y increase are equal to *vx* and *vy* respectively.

The rate at which *vx* increases is proportional to the Lorentz force in the x-direction. If the particle is in one of the Dees then the Lorentz force is only affected by the magnetic field strength. If the particle is between the Dees, the Lorentz force is only affected by the electric field strength. The Lorentz force is calculated using the custom functions *calcForce* and *eForce*. These values are then divided by mass of the particle to find the acceleration from the force.

The rate at which *vy* increases is not affected by the electric field strength, so it is calculated using *calcForce* when the particle is in one of the Dees.

The electric field vector e is given by the cosine function,

$$A \cdot \cos ft$$

where A is the variable *amp* and f is the variable *freq*.

Custom

- *calcForce* takes arguments of the current x and y position and a velocity and returns the Lorentz force acting on the particle due to the magnetic field. It uses the function *isInDee* to determine whether the particle is in one of the Dees. If the particle is not in one of the Dees, the *calcForce* returns zero.

- *eForce* returns the Lorentz force acting on the particle due to the electric field. If the particle is not in the electric field, *eForce* returns zero.
- *getX* is used to plot the Dees. Given a y-coordinate and the radius of the circle, it returns the corresponding x-coordinate.
- *isInDee* is used to determine whether the particle is in a Dee or not, by checking the x-coordinate and the y-coordinate.

Fixed Relations

The only fixed relation is to set the kinetic energy, *ke* equal to $\frac{1}{2}mv^2$.

UI

- Top panel
  The panel along the top consists of various fields and labels, as well as the play/pause button and the reset button.
- Drawing panel
  This panel consists of the drawn part of the simulation. The proton/electron particle in the system is represented by a 2dObject called 'particle'.
  - *rightDee* is a shape which is formed using the points in *semiCircX* and *semiCircY*. It is shifted to the right by 0.2.
  - *leftDee* is created using the same arrays as for *rightDee*, but it is rotated 180°.
  - *eArrow* is the arrow which displays the magnetic field vector. It is displayed at the bottom and its size is equal to the variable *e*.
  - *bArrow* is the arrow which shows the Lorentz force due to the magnetic field on the particle. It originates from the position of the particle and it's size is determined by the variables *fx* and *fy*.
  - *vArrow* is the arrow which shows the velocity of the particle. The arrow originates at the particle and its size is determined by the variables *vx* and *vy*.
- Bottom panel
  The bottom panel contains the label and field for the frequency that the electric field oscillates, given by the variable *freq*.
- Plotting dialog
  This is the window with the kinetic energy plot on it, with *ke* on the y-axis and *t* on the x-axis.

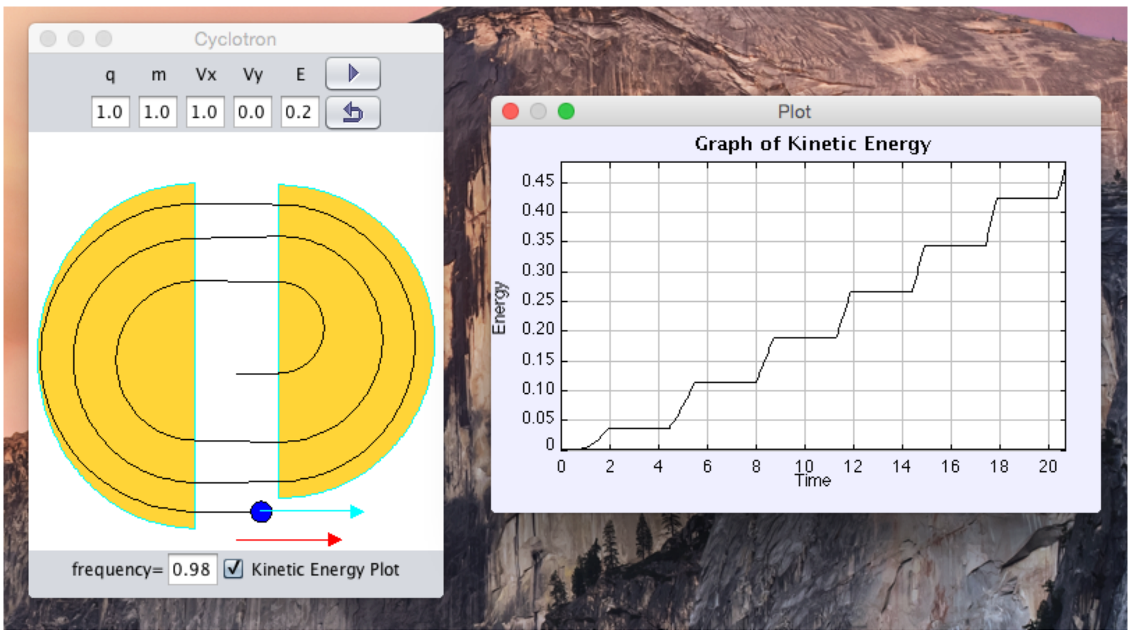

Figure 1: UI of the cyclotron experiment